Literature Review Offshore Wind Renewable Energy

This document has been prepared by the Guysborough County Inshore Fishermen's Association for aiding the regional assessment for offshore wind in Nova Scotia. It contains a collection of published literature pertaining to offshore wind energy developments. We have included the Title, Authors, Abstracts, with some commentary following of an explanation of why this article is important to us. Many of these studies identify data gaps and areas where further research is needed. Other policy related documents are included as a substitute for a Canadian version which will need to be prepared going forward. Separated into categories as follows:

Categories

1. Fishing interactions
2. Compensation/Mitigation of fishing industry
3. Ecological impacts
4. Acoustic impacts
5. Electro magnetic fields/power cables
6. Socioeconomic Reports

1. Fishing Interactions

Changes to fishing practices around the UK as a result of the development of offshore windfarms – Phase 1 (Revised). Mark Gray, Paige-Leanne Stromberg and Dale Rodmell. Gray, M., Stromberg, P-L., Rodmell, D. 2016. 'Changes to fishing practices around the UK as a result of the development of offshore windfarms – Phase 1 (Revised).' The Crown Estate, 121 pages. ISBN: 978-1-906410-64-3. The aim of this project was to determine if, and if so, to what extent and why, fishing activity has changed within the six operating offshore wind farms (OWFs) and export cable routes in the Eastern Irish Sea. Since 2000, there has been a large reduction in fishing effort and landings of demersal finfish, which was attributed to a reduction of Total Allowable Catch (TAC) and not to the installation of OWFs. Although landings of Nephrops from the Eastern Irish Sea remained fairly stable during the period before and after OWF construction, VMS data showed a decline in Nephrops trawling following the construction of Walney 2. Confidence in the evidence that suggested a decline in all types of fishing activity in the other OWFs was low to medium. Findings suggest that fishing activity within OWF boundaries has changed, primarily because fishermen are fearful of fishing gear becoming entrapped by seabed obstacles such as cables, cable crossing points and rock armouring, and wary of vessel breakdown with the consequent risk of turbine collision. Wind farm maintenance work was claimed to cause disruption to fishing (for example interrupting tows) and increasing steaming distances to fishing grounds, although fishing is not prevented within OWFs**.** The relationship between fishermen and wind farm developers and their service companies was often described as poor in terms of communication and information exchange. However, fishing was found to co-exist with OWFs. A small number of fishermen claimed to operate demersal trawl gear in cable-free corridors between the turbines (for example where interarray cables ran parallel to the trawl tracks). Other fishermen thought confidence to operate inside OWFs would increase as experience and knowledge of those who do increased. Measures suggested by respondents that could help to increase the level of co-existence between the fishing and offshore wind farm industry included: better knowledge of seabed hazards and their location; fishing-friendly methods of cable protection; monitoring of risks and exposure; and regular communication and knowledge exchange between wind farm developers / maintenance companies and fishers.

Awel y Môr Offshore Wind Farm Category 6: Environmental Statement Volume 4, Annex 8.1: Commercial Fisheries Baseline Report Date. MacNab, S. and Nimmo, F. 2022. Awel y Môr Offshore Wind Farm Commercial Fisheries Baseline Report. Report produced by Poseidon Aquatic Resources Management Ltd. This document has been prepared by Poseidon Aquatic Resource Management Ltd (Poseidon) to support the Environmental Impact Assessment (EIA) of the Awel y Môr Offshore Wind Farm (hereafter referred to as AyM). The information on commercial fisheries activity presented in this document is intended to inform the EIA for AyM by providing a detailed understanding of the commercial fisheries baseline, against which the potential impacts of AyM can be assessed. An overview of the information presented in this Technical Report is provided in Volume 2, Chapter 8: Commercial Fisheries (application ref: 6.2.8) of the Environmental Statement (ES). This document describes commercial fisheries activity, defined as fishing activity legally undertaken where the catch is sold for taxable profit. A description of charter angling activity, defined as fishing for marine species where the purpose is recreation and not sale or trade, is provided in Volume 2, Chapter 12: Other Marine Users and Activities (application ref: 6.2.12) and Appendix 12.1: Charter Angling Baseline Report (application ref: 6.4.12.1). The ecology of the fish and shellfish species targeted by commercial fishing activity is described in Volume 2, Chapter 6: Fish and Shellfish Ecology (application ref: 6.2.6).

The effects of temporary exclusion of activity due to wind farm construction on a lobster (Homarus gammarus) fishery suggests a potential management approach. Michael Roach, Mike Cohen, Rodney Forster, Andrew S. Revill, and Magnus Johnson. Offshore wind farms (OWF) form an important part of many countries strategy for responding to the threat of climate change, their development can conflict with other offshore activities. Static gear fisheries targeting sedentary benthic species are particularly affected by spatial management that involves exclusion of fishers. Here we investigate the ecological effect of a short-term closure of a European lobster (Homarus gammarus (L.)) fishing ground, facilitated by the development of the Westermost Rough OWF located on the north-east coast of the United Kingdom. We also investigate the effects on the population when the site is reopened on completion of the construction. We find that temporary closure offers some respite for adult animals and leads to increases in abundance and size of the target species in that area. Reopening of the site to fishing exploitation saw a decrease in catch rates and size structure, this did not reach levels below that of the surrounding area. Opening the site to exploitation allows the fishery to recuperate some of the economic loss during the closure. We suggest that our results may indicate that temporary closures of selected areas may be beneficial and offer a management option for lobster fisheries. We suggest if a fishing closure is also suggested in a renewable energy area, then the placement of this wind farm would be perfect in an already existing fishing closure area such as the haddock box.

Desktop study on autecology and productivity of European lobster (Homarus gammarus, L) in offshore wind farms. M.J.C. Rozemeijer, K.E. van de Wolfshaar. This desk study describes the biology of the European lobster H. gammarus. Using the obtained data a model was developed to describe the growth of the European lobster under assumed conditions on the anti-scouring of monopiles in Dutch OWFs. One of the main questions to answer was, if, theoretically, local productivity supports the continuous harvesting of lobsters with passive fishery methods.

Interaction between the Yorkshire coast static gear crustacean fishery and offshore wind energy development. Michael Roach. Abstract: Globally the offshore wind energy sector has seen an increase in the number of and spatial scale of offshore wind farms in the last decade. Offshore wind farms can be seen as many EU member states answer to meeting their energy demands from renewable sources. The increase in offshore wind developments can create spatial conflict with other marine users such as commercial fisheries. Their ecological effects on macro-benthic crustaceans are not currently widely understood. This thesis focuses on the short-term effects of the construction and operation of the Westermost Rough offshore wind farm and the subsequent closure and reopening of the site to fishing exploitation due to the construction process. There were limited effects of the Westermost Rough offshore wind farm on the size structure and catch rates of the commercially exploited crustaceans sampled over three survey years. The closure of the site during construction saw an increase in the size, abundance, and total egg yield of lobsters from the site. This increase in lobsters produced an adverse effect on the commercial bycatch species in the site. Reopening of the site to fishing exploitation, produced an immediate, short-term increase in effort. The increase in lobster size, abundance and total egg yield produced a dramatic decrease but within six weeks, reflected that of the control area. This thesis demonstrates that the there are few observable short-term effects of offshore wind farm construction on commercially exploited crustacean species. The thesis also demonstrates the effects of a closed area on commercial crustaceans and the effects of reopening the site to exploitation. The results can be used to assist in marine spatial management and future offshore wind interactions with commercially important crustacean fisheries.

Review of fish and fisheries research to inform ScotMER evidence gaps and future strategic research in the UK. Published by Marine Scotland Science. Scottish Government. This study provides a review of research of relevance to existing evidence gaps of the potential impacts of Marine Renewable Energy (MRE) developments on fish and commercial fishing in the UK, and identifies recommendations for future research to address them. The broad evidence gaps categories on which the study is focused are based on those identified by the Scottish Marine

Energy Research (ScotMER) programme's fish and fisheries evidence map. These are considered of relevance in an UK-wide context and include the following:

• FF.01: Accurate mapping of fishing effort and catches in space and time;
• FF.02: Accurate and validated method to predict fisheries displacement levels and locations;
• FF.03: Fisheries stakeholders integration and participation process;
• FF.04: Improvements in Environmental Impact Assessment methodologies;
• FF.05: Strategic fisheries management;
• FF.06: Underwater noise and vibrations;
• FF.07: Electromagnetic fields (EMF);
• FF:08: Collision risk (tidal turbines);2
• FF.09: Accurate spatio-temporal patterns of spawning activity by marine fish species;
• FF.10: Essential fish habitat (EFH);
• FF.11: Reef/fish aggregation effect;
• FF.12: Inshore populations/distribution;
• FF.13: Cumulative pressures and impact pathways;
• FF.14: Co-existence with commercial fisheries: and
• FF.15: Chemical/toxicity effects.

Research of relevance to the above evidence gaps was reviewed using internet search engines. In addition, in parallel, targeted consultation via questionnaires was undertaken with a range of UK and international experts and stakeholders including research institutions and universities, fisheries stakeholders, nature conservation organisations, developers and research and industry groups.

Residency and habitat use of European lobster (Homarus gammarus) within an offshore wind farm. H. Thatcher, T. Stamp, D. Wilcockson, and P. J. Moore. As offshore wind energy developments increase globally in response to climate change, it is important to gain an understanding of the effects they are having on the marine environment.Whilst there is growing information on the types of organisms present within these sites, our knowledge of how species interact with these sites is limited. For the first time we examined the movements and habitat utilization of a temperate decapod, the European Lobster Homarus gammarus, using acoustic telemetry within an offshore wind farm (OWF). Innovasea V9 acoustic transmitters were externally attached to 33 individuals (carapace length = 87–113 mm) at three turbine locations within an offshore wind farm in the Irish Sea. Individuals were found to exhibit high residency to the tagging sites, with over half of tagged lobsters present at the tagging sites for 70% of the study period. Individual home ranges and core territories were calculated using 95% and 50% kernel density, respectively. Home ranges ranged from 9313.76 to 23 156.48m2 while core territories ranged from 1084.05 to 6037.38m2. Over 50% of all detections were recorded within 35 m of the scour protection. These results suggest that particular areas of habitat within fixed-turbine OWFs provide a suitable habitat for lobsters. We postulate that this is likely the result of artificial reef effects arising from the addition of artificial hard substate into previously soft sediment dominated habitats. Therefore, future fixed-turbine OWF developments across Europe may provide potential fishery opportunities as a result of artificial reef effects.

Monitoring fisheries resources at offshore wind farms: BACI vs. BAG designs. Elizabeth T. Methratta. Offshore wind farms often co-occur with biodiverse marine ecosystems with high ecological, economic, and cultural value. Yet there are many uncertainties about how wind farms affect marine organisms and their environment. The before–after–control–impact (BACI) design, an approach that compares an impact location with an unaffected control both before and after the intervention, is the most common method used to study how offshore wind farms affect finfish. Unfortunately, this design has several methodological limitations that undermine its ability to detect effects in these studies. An alternative approach, the before–after-gradient (BAG) design, would sample along a gradient with increasing distance from the turbines both before and after the intervention, and could overcome many of the limitations of BACI. The BAG design would eliminate the difficult task of finding a suitable control, allow for the assessment of the spatial scale and extent of wind farm effects, and improve statistical power by incorporating distance as an independent variable in analytical models rather than relegating it to the error term. This article explores the strengths and weaknesses of the BACI and BAG designs in the context of offshore wind development and suggests an approach to incorporating the BAG design into existing fisheries surveys and a regional monitoring framework.

Fishing within offshore wind farms in the North Sea: Stakeholder perspectives for multi-use from Scotland and Germany. Maximilian Felix Schupp, Andronikos Kafas, Bela H. Buck, Gesche Krause, Vincent Onyango, Vanessa Stelzenmüller, Ian Davies, Beth E. Scott. Offshore wind power generation requires large areas of sea to accommodate its activities, with increasing claims for exclusive access. As a result, pressure is placed on other established maritime uses, such as commercial fisheries. The latter sector has often been taking a back seat in the thrust to move energy production offshore, thus leading to disagreements and conflicts among the different stakeholder groups. In recognition of the latter, there has been a growing international interest in exploring the combination of multiple maritime activities in the same area (multi-use; MU), including the re-instatement of fishing activities within, or in close proximity to, offshore wind farms (OWFs). We summarise local stakeholder perspectives from two sub-national case studies (East coast of Scotland and Germany's North Sea EEZ) to scope the feasibility of combining multiple uses of the sea, such as offshore wind farms and commercial fisheries. We combined a desk-based review with 15 semistructured qualitative interviews with key knowledge holders from both industries, regulators, and academia to aggregate key results. Drivers, barriers and resulting effects (positive and negative) for potential multi-use of fisheries and OWFs are listed and ranked (57 factors in total). Factors are of economic, social, policy, legal, and technical nature. To date, in both case study areas, the offshore wind industry has shown little interest in multiuse solutions, unless clear added value is demonstrated and no risks to their operations are involved. In contrast, the commercial fishing sector is proactive towards multi-use projects and acts as a driving force for MU developments. We provide a range of management recommendations, based on stakeholder input, to support progress towards robust decision making in relation to multi-use solutions, including required policy and regulatory framework improvements, good practice guidance, empirical studies, capacity building of stakeholders and improvements of the consultation process. Our findings represent a comprehensive depiction of the current state and key stakeholder aspirations for multi-use solutions combining fisheries and OWFs. We believe that the pathways towards robust decision making in relation to multi-use solutions suggested here are transferable to other international locations.

A framework for categorizing the interactions of offshore windfarms and fisheries Kevin D. E. Stokesbury, Gavin Fay and Robert Griffin. The offshore windfarm industry has great potential for sustainable energy but requires space. The ability of fisheries to harvest within these windfarms varies. This has created a conflict between these two industries and discussions are hampered by differing approaches to the marine environment, a lack of understanding of what each industries requires, the significant money at stake, and the values the public place on marine conservation. To characterize, standardize, and quantify the scientific data addressing these concerns requires a framework. The framework should categorize data on spatial scales of 1 cm2 to 1 km2 (individual turbines/fishing vessels), 1–1000 km2 (companies), and >1000 km2 (regions), and by their ecological, economic, cultural, and institutional impacts. The framework should be repeated over temporal scales of the windfarm: pre-development (1–3 years), construction (1–2 years), post-construction (20–40 years), and decommission. Balancing the metrics used to describe the two industries will allow people to communicate clearly in an organized systematic way, hopefully resulting in a continuing supply of sustainable sea food and renewable energy to an increasingly hungry world.

2. Compensation/Mitigation to Fishing Industry

FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Disruption Settlements and Community Funds. This document has been prepared by the Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW). Many thanks to the following organisations who were involved in drafting: National Federation of Fishermen's Organisations, RenewableUK, Scottish Renewables, Scottish Fishermen's Federation, Marine Scotland, The Crown Estate, DONG Energy, Forewind Ltd, Northern Ireland Producer's Organisation, Marine Management Organisation. Fisheries Community Funds. Settlements may be considered at the individual business or wider community level. Disruption settlements typically aim to address losses and/or costs directly incurred by individual fishing businesses through a payment to each business. Settlements at the community level are generally administered through a group arrangement. This may include the establishment of a fisheries community fund as outlined in section 6.

The following principles and considerations are likely to prove important in establishing fruitful settlements: As an alternative, or in addition to disruption settlements aimed at individual businesses, both OREI developers and fishing interests may consider it desirable to implement actions at a community level as a broader strategy to address residual impacts, or simply on the basis of a goodwill gesture in recognition of a new marine activity being accommodated within an area of existing activities.

This has led in some cases to the establishment of fisheries community funds in order to facilitate such actions. As well as supporting fishing businesses, in comparison to disruption settlements, these may also help to address less tangible but legitimate impacts and interrelationships with the wider fisheries community e.g. impacts upon the supply chain or industry support infrastructure. Existing practice in establishing such funds has generally occurred on the following basis:

Best Practice Guidance for Fishing Industry Financial and Economic Impact Assessments. Guidelines based on outputs from a technical workshop organised by the UK Fisheries Economics Network. prepared by POSEIDON AQUATIC RESOURCE MANAGEMENT LTD WINDRUSH, WARBORNE LANE PORTMORE, LYMINGTON HAMPSHIRE SO41 5RJ. Page 1 Types of impacts. See Page 25 Impacts of the Adaptions made by fishers in Response to the Intervention. UKFEN identified the need for developing best practice guidance for preparing economic impact assessments (IAs) that assess impacts on commercial fisheries as a result of areas closed or restricted to fishing. It was considered that such guidance would be beneficial to researchers, consultants, policy-makers and the industry. Poseidon was commissioned to produce a background paper that presented international examples of IAs and suggested areas where further guidance in relation to fishing would be useful. We suggest an economic impact assessment for Atlantic Canadian fisheries report be prepared.

Awel y Môr Offshore Wind Farm. Category 8: Other Documents Schedule of Mitigation. This document lists all the mitigation proposed in the Environmental Impact Assessment (EIA) for Awel y Môr (AyM). The following schedule lists all measures proposed and signposts where the commitments made in the Environmental Statement (ES) are secured in the draft Development Consent Order (DCO) and associated documents. As a result of the parallel DCO and Marine Licence application processes, signposting offshore-specific mitigation measures to draft marine licence conditions is not possible. Mitigation measures of relevance to marine licencing are included in the Marine Licence Principles Document. This document contains specific details about mitigation measures during construction phases occurring onshore and offshore. Page 19 contains details about offshore mitigation measures recording power cables will be buried to a max target of 4m depth. Page 21 sets max threshold for pile driving activities and details regarding disposal site for dredged materials being within the renewable energy leased site. Rarely are specific mitigation techniques detailed in our Nova Scotia EA documentation which leaves a lack of transparency and possible unsubstantiated concerns from citizens.

FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Liaison. Dot Davies Secretariat The Fishing Liaison with Offshore Wind and Wet Renewables Group c/o The Crown Estate 6 Bell's Brae Edinburgh EH4 3BJ. The Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW) was set up in 2002 to foster good relations between the fishing and offshore renewable energy sectors and to encourage co-existence between both industries. FLOWW's objectives are to enable and facilitate discussion discuss on matters arising from the interaction of the fishing and offshore renewable energy industries, to promote and share best practice, and to encourage liaison with other sectors in the marine environment. FLOWW comprises organisations with an interest in offshore renewables and the fishing industry, being comprised of fishing industry bodies, offshore renewable developers and consultants, government agencies and The Crown Estate. The group is facilitated by a secretariat funded by The Crown Estate.

Cumulative Historic Resources Visual Effects Analysis – Revolution Wind Farm and Revolution Wind Export Cable Project. PREPARED FOR U.S. Department of the Interior, Bureau of Ocean Energy Management, Office of Renewable Energy Programs PREPARED BY SWCA Environmental Consultants. The Bureau of Ocean Energy Management (BOEM), with contractor support from SWCA Environmental Consultants (SWCA), prepared this cumulative historic resources visual effects analysis (CHRVEA) for the Revolution Wind Farm (RWF) and Revolution Wind Export Cable Project (the Project). BOEM has determined that the Project has the potential to contribute to the cumulative visual effects on historic properties (as defined at 36 CFR 800.16(l)) in combination with the potential effects of other proposed actions, most specifically other offshore wind energy development activities in the geographic analysis area (GAA). In considering the potential for cumulative visual effects of the Project on historic properties, including National Historic Landmarks (NHLs, as defined at 36 CFR 800.16(p)), the CHRVEA assists BOEM in complying with Sections 106 and 110(f) of the National Historic Preservation Act (NHPA), as amended (54 USC 306108 and 54 USC 306107), and the implementing regulations for the Section 106 process (36 CFR 800). At 36 CFR 800.10, the Section 106 regulations provide Special requirements for protecting National Historic Landmarks that reemphasize compliance with Section 110(f), for the agency "to the maximum extent possible, undertake such planning and actions as may be necessary to minimize harm to any National Historic Landmark that may be directly and adversely affected by an undertaking." The onshore and offshore historic resources visual effects analysis (HRVEA) reports prepared for the Project by the lessee (Revolution Wind, LLC) identify historic properties (including NHLs) within a preliminary area of potential effects (APE) for visual effects analysis, the area within which visual adverse effects could result from wind turbine generator (WTG) installation (Environmental Design and Research [EDR] 2021a, 2021b, 2022a, 2022b). In a review of the HRVEA reports for the Project, BOEM has determined that the Project would result in potential visual adverse effects to the 101 historic properties within the preliminary APE of coastal Massachusetts and Rhode Island. Although the APE extends to Connecticut and Long Island, New York, no historic properties were determined to be adversely affected in those states. As BOEM presented to NHPA Section 106 consulting parties on maps in a meeting on December 17, 2021, the GAA for the National Environmental Policy Act (NEPA) analysis and the APE for the NHPA Section 106 review are the same areas. BOEM plans to delineate the final area of potential effects (APE) with releases of the finding of effect report, and this report will be shared with the consulting parties for their review and comment before the draft environmental impact statement (EIS) is issued publicly. BOEM has elected to use the NEPA substitution process for Section 106 purposes pursuant to 36 CFR 800.8(c).

Among the 101 adversely affected historic properties, the offshore HRVEA identifies five NHLs in Rhode Island and two traditional cultural properties (TCPs) in Massachusetts that would be adversely affected by the Project in the APE (EDR 2022a, 2022b). Th five NHLs consist of Block Island Southeast Lighthouse, Ocean Drive Historic District, Bellevue Avenue Historic District, The Breakers, and Marble House. Each of the 101 historic properties noted above retains its maritime setting, and that maritime setting contributes to the property's NRHP eligibility and continues to offer significant seaward views. These seaward views support the integrity of the maritime setting and include vantage points with the potential for an open view from each property toward RWF WTGs (EDR 2021b, 2022a). The Project would contribute proportionally between nearly 10 and nearly 90 percent of the cumulative adverse effect, owing to the location and intensity of the foreseeable build-out attributed to other offshore wind energy development activities relative to the location of the historic property. This is based on full buildout of the Project (to up to 100 WTGs and two offshore substations [OSS]) and all other reasonably foreseeable offshore wind projects currently planned in the adjacent lease areas (modeled at 955 WTG and three OSS [EDR 2021b]). The proportion of visible WTG elements added by the project ranges from 9.6 percent at TCP, where all modeled WTGs and OSS would I Cumulative Historic Resources Visual Effects Analysis – Revolution Wind Farm and Revolution Wind Export Cable Project potentially be visible, to 87.2 percent at the historic U.S. Weather Bureau Station at Block Island, where the Project WTGs would be visible in greater numbers than the combination of all other future wind farms planned in adjacent OCS lease areas (41 Project WTGs would potentially be visible there versus six WTGs from other planned projects).

Intensity of visual impacts from WTG and offshore substation development would reduce with distance from historic properties and with lighting and design actions that would be undertaken by the Project to minimize impacts; however, cumulative adverse effects would not be fully eliminated at the 101 adversely affected historic properties. This CHRVEA recommends BOEM consider additional mitigation to be determined in BOEM's consultation with consulting parties.

The CHRVEA assesses the Project's offshore elements' cumulative visual effects (daytime and nighttime) on historic properties when combined with past, present, and reasonably foreseeable offshore wind energy development activities in the APE for the Project. CHRVEA analyses inform BOEM's determination of overall Project effects on historic properties and consultation on those effects. BOEM plans to provide the finding of effect report to the consulting parties before the Project EIS. BOEM remains in consultation with all consulting parties under Section 106 of the NHPA, including Native American Tribal Nations that may have concerns for properties of traditional cultural and religious significance in the APE; State Historic Preservation Offices/Division for Historic Preservation; Advisory Council on Historic Preservation; National Park Service; and other cooperating federal agencies, local governments, and historical interest groups. BOEM will continue to consult with these parties on this assessment of cumulative effects and the resolution of all adverse effects. BOEM will continue to consult with the consulting parties to resolve the adverse effects through avoidance, minimization, and mitigation measures by executing a memorandum of agreement or listing the resolution measures in the record of decision pursuant to 36 CFR 800.8(c) because BOEM has elected to use the NEPA substitution for this Section 106 consultation.

Community Benefits Agreement Toolkit. http://www.actiontankusa.org Toolkit adapted from research and resources on Community Benefits Agreements provided by PolicyLink and Julian Gross**.** Sponsored by **http://www.stephenhwilderfoundation.org/**

Crossed Wires: Maintaining public support for offshore wind farms Ed Birkett Foreword by Rt Hon Dame Andrea Leadsom DBE MP and Rt Hon Amber Rudd. Policy Exchange is the UK's leading think tank. We are an independent, non-partisan educational charity whose mission is to develop and promote new policy ideas. The Government's target to install 40 gigawatts (GW) of offshore wind by 2030 requires a step change in the development of Great Britain's onshore and offshore electricity networks. Without reform, there is now a significant risk that local backlash against grid connections for offshore wind farms will grow, spreading from East Anglia to North Wales, Humberside, and the east coast of Scotland. With the right reforms, the Government can ensure that offshore wind maintains the strongest possible support across the UK, recognising that compensation should be forthcoming for those local communities that will be inevitably impact by new infrastructure, even under a coordinated approach. As the offshore wind rollout continues, there will be plenty of opportunities for British businesses to participate, whether manufacturing of wind turbines and subsea cables, constructing and operating wind farms, or developing the new technologies that will unlock an offshore electricity grid in the North Sea. Therefore, alongside the reforms proposed in this report, the Government should ensure that British businesses have the right opportunities to win contracts, grow green jobs and expand the export potential of the UK's world-leading offshore wind industry.

3. Ecological Impacts

Could federal wind farms influence continental shelf oceanography and alter associated ecological processes? A literature review. Travis Miles, Sarah Murphy, Josh Kohut, Professor, Sarah Borsetti, Daphne Munroe, Associate Professor. As of the draft of this document, the US east coast has 1.7 million acres of federal bottom under lease for development of wind energy installations, with plans for more than 1,500 foundations to be placed. The scale of the impact of these wind farms has the potential to alter the unique and delicate oceanographic conditions along the expansive Atlantic continental shelf, a region characterized by a strong seasonal thermocline that overlies cold bottom water, known as the "Cold Pool." Strong seasonal stratification traps cold (typically less than 10°C) water above the ocean bottom sustaining a boreal fauna whose range extends farther south than would be anticipated by latitude. This boreal fauna represents vast fisheries, including the most lucrative shellfish fisheries in the U.S. In this report, we review the existing literature and research pertaining to the ways in which offshore wind farms may alter processes that establish, maintain, and degrade stratification associated with the Cold Pool through vertical mixing in this seasonally dynamic system. Changes in stratification could have important consequences in Cold Pool set-up and degradation, a process fundamental to the high fishery productivity of the region. While still limited, there is an increasing body of research focused on the specific processes that describe the interaction between offshore wind turbines and underlying ocean conditions, at scales ranging from individual turbines to entire wind farms. These studies have examined turbulent mixing generated by turbine structure, wind extraction reducing surface wind stress and altering water column turbulence. These mechanisms could influence ocean mixing and in turn stratification that is a key characteristic of the Cold Pool. The majority of research to date on offshore wind turbine effects on ocean mixing were carried out in, or simulated to represent, coastal waters around Northern Europe. It is important to recognize that the oceanographic conditions specific to these European study sites differ in many important ways compared to that of the Mid Atlantic Bight Cold Pool. Generally, continental shelf waters in Northern Europe are less stratified seasonally and have stronger tidal currents (and higher turbulence) than those of the Mid Atlantic Bight. Thus, results from the European studies characterizing potential impacts of offshore wind facilities on stratification are more representative of impacts we might expect during the relatively weaker stratified time periods in spring and fall (during Cold Pool set up and breakdown, respectively). During the highly stratified summer months, previous results suggest it is less likely that the structures will induce mixing sufficient to overcome the strong stratification and impact Cold Pool integrity, nor the broad exchange between the surface and bottom water layers.
Nonetheless, the potential for these multiple wind energy arrays to alter oceanographic processes, and the biological systems that rely on them is possible; however, a great deal of uncertainty remains about the nature and scale of these interactions. We suggest that research should be prioritized that identifies stratification thresholds of influence, below which turbines

and wind farm arrays may alter oceanographic processes, and these should be examined within context of spatial and seasonal dynamics of the Cold Pool and offshore wind lease areas to identify potential areas of further study.

Accelerating deployment of offshore wind energy alter wind climate and reduce future power generation potentials. Institute of Coastal Systems-Analysis and Modeling, Helmholtz-Zentrum Hereon, Geesthacht, Germany. The European Union has set ambitious CO2 reduction targets, stimulating renewable energy production and accelerating deployment of offshore wind energy in northern European waters, mainly the North Sea. With increasing size and clustering, offshore wind farms (OWFs) wake effects, which alter wind conditions and decrease the power generation efficiency of wind farms downwind become more important. We use a high-resolution regional climate model with implemented wind farm parameterizations to explore offshore wind energy production limits in the North Sea. We simulate near future wind farm scenarios considering existing and planned OWFs in the North Sea and assess power generation losses and wind variations due to wind farm wake. The annual mean wind speed deficit within a wind farm can reach 2–2.5 ms^{-1} depending on the wind farm geometry. The mean deficit, which decreases with distance, can extend 35–40 km downwind during prevailing southwesterly winds. Wind speed deficits are highest during spring (mainly March–April) and lowest during November–December. The large-size of wind farms and their proximity affect not only the performance of its downwind turbines but also that of neighboring downwind farms, reducing the capacity factor by 20% or more, which increases energy production costs and economic losses. We conclude that wind energy can be a limited resource in the North Sea. The limits and potentials for optimization need to be considered in climate mitigation strategies and cross-national optimization of offshore energy production plans are inevitable.

Convergence of emerging technologies: Development of a risk-based paradigm for marine mammal monitoring for offshore wind energy operations. Abstract: The ability to gather real-time and near real-time data on marine mammal distribution, movement, and habitat use has advanced significantly over the past two decades. These advances have outpaced their adoption into a meaningful, risk based assessment framework so critically needed to support society's growing demands for a transition to increased reliance on renewable energy. Marine acoustics have the capacity to detect, identify, and locate vocalizations over broad areas. Photogrammetric and image processing increases the ability to visually detect animals from surface or aerial platforms. Ecological models based on long-term observational data coupled with static and remotely sensed oceanographic data are able to predict daily and seasonal habitat suitability. Extensive monitoring around anthropogenic activities, combined with controlled experiments of exposure parameters (i.e., sound), supports better informed decisions on reducing effects. Population models and potential consequence modeling provide the ability to estimate the significance of individual and population exposure. The collective capacities of these emerging technical approaches support a risk ranking and risk management approach to monitoring and mitigating effects on marine mammals related to development activities. The monitoring paradigm related to many offshore energy-related activities, however, has long been spatially limited, situationally myopic, and operationally uncertain. A case evaluation process is used to define and demonstrate the changing paradigm of effective monitoring aimed at protecting living resources and concurrently providing increased certainty that essential activities can proceed efficiently. Recent advances in both technologies and operational approaches are examined to delineate a risk-based paradigm, driven by a diversity of regional data inputs, that is capable of meeting the imperative for timely development of offshore wind energy. Integr Environ Assess Manag 2022;18:939–949. © 2021

The 2020 State of the Science report was produced by the Ocean Energy Systems (OES)-Environmental initiative (formerly Annex IV), under the International Energy Agency's OES-Environmental collaboration (https://www.ocean-energy-systems.org). https://tethys.pnnl.gov/publications/state-of-the-science-2016.

The outsized trophic footprint of marine urbanization. Martino E Malerba, Craig R White, and Dustin J Marshall. Artificial structures are proliferating along coastlines worldwide, creating new habitat for heterotrophic filter feeders. The energy demand of this heterotrophic biomass is likely to be substantial, but is largely unquantified. Combining in situ surveys, laboratory assays, and information obtained from geographic information systems, we estimated the energy demands of sessile invertebrates found on marine artificial structures worldwide. At least 950,000 metric tons of heterotrophic biomass are associated with commercial ports around the world, emitting over 600 metric tons of carbon dioxide into the atmosphere and consuming 5 million megajoules of energy per day. We propose the concept of a trophic "footprint" of marine urbanization, in which every square meter of artificial structure can negate the primary production of up to 130 square meters of surrounding coastal waters; collectively, these structures not only act as energy sinks and carbon sources, but also potentially reduce the productivity of coastal food webs. Front Ecol Environ 2019

Potential environmental effects of deepwater floating offshore wind energy facilities Hayley Farr [a,1,*], Benjamin Ruttenberg [a,b], Ryan K. Walter [b,c], Yi-Hui Wang [a,b], Crow White [a,b]
Abstract: Over the last few decades, the offshore wind energy industry has expanded its scope from turbines mounted on foundations driven into the seafloor and standing in less than 60 m of water, to floating turbines moored in 120 m of water, to prospecting the development of floating turbines moored in ~1,000 m of water. Since there are few prototype turbines and mooring systems of these deepwater, floating offshore wind energy facilities (OWFs) currently deployed, their effects on the marine environment are speculative. Using the available scientific literature concerning appropriate analogs, including fixed-bottom OWFs, land-based wind energy facilities, wave and tidal energy devices, and oil and gas platforms, we conducted a qualitative systematic review to estimate the potential environmental effects of deepwater, floating OWFs during operation, as well as potential mitigation measures to address some of the effects. We evaluated six categories of potential effects: changes to atmospheric and oceanic dynamics due to energy removal and modifications, electromagnetic field effects on

marine species from power cables, habitat alterations to benthic and pelagic fish and invertebrate communities, underwater noise effects on marine species, structural impediments to wildlife, and changes to water quality. Our synthesis of 89 articles selected for the review suggests that many of these potential effects could be mitigated to pose a low risk to the marine environment if developers adopt appropriate mitigation strategies and best-practice protocols. This review takes the necessary first steps in summarizing the available information on the potential environmental effects of deepwater, floating OWFs and can serve as a reference document for marine scientists and engineers, the energy industry, permitting agencies and regulators of the energy industry, project developers, and concerned stakeholders such as coastal residents, conservationists, and fisheries.

Preliminary Data Aggregation and Analysis of the Effects on Fish, Marine Mammals, and other Marine Organisms, and the Habitats that Support them, from a Proposed Offshore Wind Farm off the Coast of Grays Harbor, Washington. January 2022. Pacific Northwest National Laboratory Seattle, Washington 98109. The Pacific Northwest National Laboratory (PNNL) was contracted by Herrera Environmental Consultants, Inc. on behalf of GHW to carry out this preliminary scoping study to evaluate baseline conditions and potential effects on fish and marine mammals from development and operation of a floating offshore wind farm installed within a designated area off the coast of Washington1. Many of the studies available in the published literature have been conducted on behalf of a renewable energy company. Large numbers of recent studies draw conclusions based on computer models as the lack of empirical data from actual wind farms are not yet available.

WORKING GROUP ON MARINE BENTHAL AND RENEWABLE ENERGY DEVELOPMENTS (WGMBRED) ICES. 2021. Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED). ICES Scientific Reports. 3:63. 24 pp. https://doi.org/10.17895/ices.pub.8209. The aim of the Working Group on Marine Benthal and Renewable Energy Developments (WGMBRED) is to increase scientific exchange and efficiency of benthal renewable energy related research. In 2019–2021, the group discussed guidelines for data collection and methodologies and developed an integrated example dataset on benthos data of marine renewable energy devices. This database CRITTERBASE, currently contains data from Belgium, the Netherlands, Germany and Denmark on wind farms, gas platforms and a natural reef, based on 1969 samples collected during 92 expeditions with 710 benthic taxa. This dataset will be made publicly available to serve future research on the effects of the installation and exploration of renewable energy devices in the marine environment.

WGMBRED further investigated possible positive effects of renewable energy installations, developed the scientific basis for assessing the effect of different decommissioning scenarios and reviewed the available knowledge on the relationship between renewable energy installations and the provisioning of ecosystem services. The identified positive effects of the installation of offshore energy devices is linked with the removal of pressures in light of safety issues, rather than a direct protection of the marine environment, and therefore such installations can be considered as Other Effective area-based Conservation Measure (OECM). The group identified the most plausible decommissioning scenarios and tested whether the earlier published cause-effect relationships underlying the effect of the presence of renewable energy installations can be used – after slight modification – for assessing the (partial) removal of the devices.

Along the same lines, a structural review of the biodiversity – ecosystem functioning – ecosystem service links in the context of an operational phase of an offshore wind farm resulted in a conceptual framework and available knowledge base allowing formal semi-quantitative analyses. WGMBRED will continue along these lines and use the concepts and collective knowledge base for more formal assessments of the ecological consequences of installing, operating and decom-missioning renewable energy structures from the marine environment. In addition, WGMBRED will review emerging non-invasive monitoring techniques and methodology to assess the effect of energy emissions on the environment.

Multi-modal Approach for Benthic Impact Assessments in Moraine Habitats: A Case Study at the Block Island Wind Farm. https://link.springer.com/article/10.1007/s12237-020-00818-w Benthic assessment techniques utilized in soft sediment areas are of limited utility in glacial moraine habitats that are structurally complex and largely composed of hard substrata. We present a multi-modal approach consisting of multibeam bathymetry, video, and still imagery that collectively provides the knowledge base necessary to perform impact assessments in these habitats. Baseline and post-construction surveys were conducted adjacent to the Block Island Wind Farm to develop and test these methodologies within the context of offshore wind development, specifically for detecting and documenting anchoring-related impacts to moraine habitats. Habitat data were evaluated using the substrate and biotic components of the national classification standard, the Coastal and Marine Ecological Classification Standard, recommended by federal regulators, with modifications to present results in terms of predicted vulnerability to disturbance. Habitats near the wind farm were diverse and patchy, ranging from rippled gravelly sand to continuous cobble/boulder fields with high biotic cover. Anchor furrows were detected in moderate value habitats in bathymetric and video data. The multi-modal survey approach tested at the Block Island Wind Farm and presented here is now specifically recommended by federal agencies and is being used to inform efforts currently underway to map and assess benthic habitats for a number of U.S. projects seeking federal permits.

Characterizing the benthic community in Maryland's offshore wind energy areas using a towed camera sled: Developing a method to reduce the effort of image analysis and community description. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0215966#pone-0215966-g004 Offshore wind farms are a crucial component for the improvement of renewable energy in the United States. The Bureau of Ocean Energy Management (BOEM) designated ~170 km2 of shelf area for wind energy development off the coast of Maryland, USA. In order to understand potential environmental impacts of wind turbine installation on the benthic ecosystem within the designated area, we conducted a study to visually characterize bottom habitats and epibenthic communities in the Mid-Atlantic Outer Continental Shelf blocks of the Maryland wind energy area. Seven 5 km long transects were sampled using a towed camera sled with a downward-facing digital camera that captured images at 5 frames·s-1s. Additional small-mesh beam trawling was also conducted at selected locations complementary for species identification. Image data were analyzed using two image selection methods, random and systematic (i.e. video frames were selected at various intervals). For both methods, estimates of community diversity (Hill's N2) stabilized with sample sizes ranging from 316 to 398 frames. Our results allowed us to define distinct epibenthic communities and bottom habitats that are associated with offshore wind energy sites and to develop a sampling technique for digital images that can be applied to other research programs.

Oceanic records of North American bats and implications for offshore wind energy development in the United States. Donald I. Solick, Christian M. Newman. Abstract: Offshore wind energy is a growing industry in the United States, and renewable energy from offshore wind is estimated to double the country's total electricity generation. There is growing concern that land-based wind development in North America is negatively impacting bat populations, primarily long-distance migrating bats, but the impacts to bats from offshore wind energy are unknown. Bats are associated with the terrestrial environment but have been observed over the ocean. In this review, we synthesize historic and contemporary accounts of bats observed and acoustically recorded in the North American marine environment to ascertain the spatial and temporal distribution of bats flying offshore. We incorporate studies of offshore bats in Europe and of bat behaviour at land-based wind energy studies to examine how offshore wind development could impact North American bat populations. We find that most offshore bat records are of long-distance migrating bats and records occur during autumn migration, the period of highest fatality rates for long-distance migrating bats at land-based wind facilities in North America. We summarize evidence that bats may be attracted to offshore turbines, potentially increasing their exposure to risk of collision. However, higher wind speeds offshore can potentially reduce the amount of time that bats are exposed to risk. We identify knowledge gaps and hypothesize that a combination of operational minimization strategies may be the most effective approach for reducing impacts to bats and maximizing offshore energy production.

4. Acoustic Impacts

In 2008, Germany became the first nation worldwide to define an underwater noise limit at SEL 160db (sound exposure level) and SPL 190dB (sound peak level) at a distance of 750m from the

sound source. Setting of EU Threshold Values for impulsive underwater sound. Recommendations from the Technical Group on Underwater Noise (TG Noise) MSFD Common Implementation Strategy Technical Group on Underwater Noise (TG NOISE) Deliverable 2 of the work programme of TG Noise 2022
https://environment.ec.europa.eu/news/zero-pollution-and-biodiversity-first-ever-eu-wide-limits-underwater-noise-2022-11-29_en

https://circabc.europa.eu/ui/group/326ae5ac-0419-416783cae3c210534a69/library/edd5bf34-f124-4689-9bba-f754259e0b9f/details

Acoustic Masking in Marine Ecosystems, intuitions, analysis, and implication. Clark et al.

Stress response to anthropogenic noise in Atlantic cod, Gadus morhua L. Rogelio Sierra-Flores, Tim Atack, Hervé Migaud, Andrew Davie. The potential effects of anthropogenic noise on the physiology of Atlantic cod have not been well described. The aim of the present study was to investigate the impact of anthropogenic noise on Atlantic cod stress response using cortisol as a biomarker as well as on broodstock spawning performance. Results showed that artificial noise consisting of a linear sweep from 100 to 1000 Hz can induce a transient and mild cortisol elevation with a clear noise intensity dose response. In all cases plasma levels returned to baseline levels <1 h post sound exposure. Daily exposure to a similar intensity and frequency noise range applied habitually to a broodstock population during the spawning window resulted in a significant reduction in total egg production and fertilisation rates thus reducing the total production of viable embryos by over 50%. In addition, a significant negative correlation between egg cortisol content and fertilisation rate was observed. These results confirm that cod can perceive noise generated within a frequency range of 100–1000 Hz and display a heightened cortisol plasma level. In addition, anthropogenic noise can have negative impacts on cod spawning performances. It is important to note that several other commercially important fish such as herring are also sensitive to sound and vibration.

Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. P. T. Madsen1,*, M. Wahlberg2, J. Tougaard3, K. Lucke4, P. Tyack1
ABSTRACT: The demand for renewable energy has led to construction of offshore wind farms with high-power turbines, and many more wind farms are being planned for the shallow waters of the world's marine habitats. The growth of offshore wind farms has raised concerns about their impact on the marine environment. Marine mammals use sound for foraging, orientation and communication and are therefore possibly susceptible to negative effects of man-made noise generated from constructing and operating large offshore wind turbines. This paper reviews the existing literature and assesses zones of impact from different noise-generating activities in conjunction with wind farms on 4 representative shallow-water species of marine mammals. Construction involves many types of activities that can generate high sound pressure levels, and pile-driving seems to be the noisiest of all. Both the literature and modeling show that pile-driving and other activities that generate intense impulses during construction are likely to disrupt the behavior of marine mammals at ranges of many kilometers, and that these activities have the potential to induce hearing impairment at close range. The reported noise

levels from operating wind turbines are low, and are unlikely to impair hearing in marine mammals. The impact zones for marine mammals from operating wind turbines depend on the low-frequency hearing-abilities of the species in question, on sound-propagation conditions, and on the presence of other noise sources such as shipping. The noise impact on marine mammals is more severe during the construction of wind farms than during their operation.

Low-frequency noise pollution impairs burrowing activities of marine benthic invertebrates☆
Sheng V. Wang, Alexa Wrede, Nelly Tremblay, Jan Beermann.
Abstract: Sounds from human activities such as shipping and seismic surveys have been progressively invading natural soundscapes and pervading oceanic ambient sounds for decades. Benthic invertebrates are important ecosystem engineers that continually rework the sediment they live in. Here, we tested how low-frequency noise (LFN), a significant component of noise pollution, affects the sediment reworking activities of selected macrobenthic invertebrates. In a controlled laboratory setup, the effects of acute LFN exposure on the behavior of three abundant bioturbators on the North Atlantic coasts were explored for the first time by tracking their sediment reworking and bioirrigation activities in noisy and control environments via luminophore and sodium bromide (NaBr) tracers, respectively. The amphipod crustacean *Corophium volutator* was negatively affected by LFN, exhibiting lower bioturbation rates and shallower luminophore burial depths compared to controls. The effect of LFN on the polychaete *Arenicola marina* and the bivalve *Limecola balthica* remained inconclusive, although *A. marina* displayed greater variability in bioirrigation rates when exposed to LFN. Furthermore, a potential stress response was observed in *L. balthica* that could reduce bioturbation potential. Benthic macroinvertebrates may be in jeopardy along with the crucial ecosystem-maintaining services they provide. More research is urgently needed to understand, predict, and manage the impacts of anthropogenic noise pollution on marine fauna and their associated ecosystems.

Sound detection by the American lobster (Homarus americanus) Youenn Jézéquel, Ian T. Jones, Julien Bonnel, Laurent Chauvaud, Jelle Atema and T. Aran Mooney
Abstract - Although many crustaceans produce sounds, their hearing abilities and mechanisms are poorly understood, leaving uncertainties regarding whether or how these animals use sound for acoustic communication. Marine invertebrates lack gas-filled organs required for sound pressure detection, but some of them are known to be sensitive to particle motion. Here, we examined whether the American lobster (Homarus americanus) could detect sound and subsequently sought to discern the auditory mechanisms. Acoustic stimuli responses were measured using auditory evoked potential (AEP) methods. Neurophysiological responses were obtained from the brain using tone pips between 80 and 250 Hz, with best sensitivity at 80–120 Hz. There were no significant differences between the auditory thresholds of males and females. Repeated controls (recordings from deceased lobsters, moving electrodes away from the brain and reducing seawater temperature) indicated the evoked potentials' neuronal origin. In addition, AEP responses were similar before and after antennules (including statocysts) were ablated, demonstrating that the statocysts, a long-proposed auditory structure in crustaceans, are not the sensory organs responsible for lobster sound detection. However, AEPs could be eliminated (or highly reduced) after immobilizing hairfans, which cover much of lobster bodies.

These results suggest that these external cuticular hairs are likely to be responsible for sound detection, and imply that hearing is mechanistically possible in a wider array of invertebrates than previously considered. Because the lobsters' hearing range encompasses the fundamental frequency of their buzzing sounds, it is likely that they use sound for intraspecific communication, broadening our understanding of the sensory ecology of this commercially vital species. The lobsters' low-frequency acoustic sensitivity also underscores clear concerns about the potential impacts of anthropogenic noise.

Effects of pile driving sound playbacks and cadmium co-exposure on the early life stage development of the Norway lobster, *Nephrops norvegicus* C.A. Stenton, E.L. Bolger, M. Michenot, J.A. Dodd, M.A. Wale, R.A. Briers, M.G.J. Hartl, K. Diele. Abstract There is an urgent need to understand how organisms respond to multiple, potentially interacting drivers in today's world. The effects of the pollutants anthropogenic sound (pile driving sound playbacks) and waterborne cadmium were investigated across multiple levels of biology in larval and juvenile Norway lobster, *Nephrops norvegicus* under controlled laboratory conditions. The combination of pile driving playbacks (170 dBpk-pk re 1 µPa) and cadmium combined synergistically at concentrations >9.62 µg[Cd] L⍰ 1 resulting in increased larval mortality, with sound playbacks otherwise being antagonistic to cadmium toxicity. Exposure to 63.52 µg[Cd] L⍰ 1 caused significant delays in larval development, dropping to 6.48 µg[Cd] L⍰ 1 in the presence of piling playbacks. Pre-exposure to the combination of piling playbacks and 6.48 µg[Cd] L⍰ 1 led to significant differences in the swimming behaviour of the first juvenile stage. Biomarker analysis suggested oxidative stress as the mechanism resultant deleterious effects, with cellular metallothionein (MT) being the predominant protective mechanism.

Effects of Offshore Wind Farm Noise on Marine Mammals and Fish. Thomsen, F., Lüdemann, K., Kafemann, R. and Piper, W. (2006). Executive Summary: Since the beginning of the planning and installation of offshore wind farms, the possible impacts on marine mammals and fish have been discussed intensively within the public and the scientific community. Especially the noise created during pile-driving operations involves sound pressure levels that are high enough to impair the hearing system of marine mammals near the source and disrupt their behaviour at considerable distance from the construction site. Previous investigations also indicated that the construction phase will have considerable effects on fish species common in northern European waters. The goal of this study was to provide a further assessment on the effects of offshore wind farm related noise on selected marine mammal and fish species.

Measurements of pile-driving noise were obtained as peak sound pressure levels and sound exposure levels in 1/3 octave bands from a jacket-pile construction in the German Bight. Operational noise was measured in peak sound pressure levels and equivalent sound pressure levels in 1/3 octave bands in 110 m distance from a 1.5 MW turbine in Sweden. Based on these measurements, sound levels at various distances from the source were calculated and zones of noise influences were assessed based on published data.

The broadband peak sound pressure level during pile-driving was 189 dB0-p re 1 µPa (SEL = 166 dB re 1 µPa2 . s) at 400 m distance, resulting in a peak broadband source level of 228 dB0-p re 1 µPa at 1 m (SEL = 206 dB re 1 µPa2 . s at 1 m). The 1/3 octave sound pressure level was highest at 315 Hz (peak = 218 dB0-p re 1 µPa at 1 m) with considerable pressures above 2 kHz.

Values for the impact assessment were extrapolated for larger pile-diameters after recent measurements performed in the same area. During operation, the 1/3 octave sound pressure levels ranged between < 90 and 142 dBLeq re 1 µPa at 1m with most energy at 50, 160 and 200 Hz, at wind-speeds of 12 m/s.
For harbour porpoises and harbour seals, the zone of audibility for pile-driving will most certainly extend well beyond 80 km, perhaps hundreds of kilometres from the source. Behavioural responses are possible over many kilometres, perhaps up to ranges of 20 km. Masking might occur in harbour seals at least up to 80 km and hearing loss might be a concern – on the basis of a regulatory approach - at 1.8 km in porpoises and 400 m in seals. Further, severe injuries in the immediate vicinity of ramming activities can not be ruled out. Operational noise of smaller turbines of 1.5 MW should have only minor influence as the detection radii for both species are rather small. However, since operational noise of larger turbines can not be assessed reliably yet, these results are rather preliminary. It is very likely that larger turbines are noisier resulting in much larger zones of noise influence.
Cod and herring will be able to perceive piling noise at large distances, perhaps up to 80 km from the sound source. Dab and salmon might detect pile-driving pulses also at considerable distances from the source. However, since both species are predominantly sensitive for particle motion and not pressure, the detection radius can not be defined yet. Behavioural effects are possible due to piling noise. The spatial extension of the zone of responsiveness can not be calculated, as the available threshold levels vary greatly. The zone of potential masking might in some cases coincides with the zone of audibility. Also physical effects, like internal or external injuries or deafness (TTS/PTS) up to cases of mortality, are possible in the close vicinity to piledriving.
Operational noise of wind turbines will be detectable up to a distance of app. 4 km for cod and herring, and probably up to 1 km for dab and salmon. Within this zone, also masking of intraspecific communication is possible. Behavioural and/or physiological (stress) effects are possible due to operational wind farm noise. However, they should be restricted to very close ranges.

A fine-scale marine mammal movement model for assessing long-term aggregate noise exposure. Ruth Joy, Robert S. Schick, Michael Dowd, Tetyana Margolina, John E. Joseph, Len Thomas. Understanding the impacts of anthropogenic sound on marine mammals is important for effective mitigation and management. Sound impacts can cause behavioral changes that lead to displacement from preferred habitat and can have negative influence on vital rates. Here, we develop a movement model to better understand and simulate how whales respond to anthropogenic sound over ecologically meaningful space and time scales. The stochastic model is based on a sequential Monte Carlo sampler (a particle filter). The movement model takes account of vertical dive information and is influenced by the underwater soundscape and the historical whale distribution in the region. In the absence of noise disturbance, the simulator is shown to recover the historical whale distribution in the region. When noise disturbance is incorporated, the whale's behavioral response is determined through a dose response function dependent on the received level of sound. The aggregate impact is assessed by considering both the duration of foraging loss and the spatial shift to alternate (and potentially less favorable) habitat. Persistence of the behavioral response in time is treated through a 'disruption' parameter. We apply the approach to a population of fin whales whose distribution overlaps naval sonar testing activities beside the Southern California range complex. The simulation shows the consequences of one year of naval sonar disturbance are a function of: i) how loud the sound source is, ii) where the disturbed whales are relative to preferred (high density) habitat, and iii) how long a whale takes before returning to a pre-disturbance state. The movement simulator developed here is a generic movement modeling tool that can be adapted for different species, different regions, and any acoustic disturbances with known impacts on animal populations.

5. Electromagnetic Fields/Power Cables

Review of the effects of underwater sound, vibration and electromagnetic fields on crustaceans. May 2020. Dr Kevin Scott, Althea JR Piper, Erica CN Chapman, and Corentine MV Rochas. Scott, K., Piper, A.J.R. Chapman, E.C.N. & Rochas, C.M.V., 2020. Review of the effects of underwater sound, vibration and electromagnetic fields on crustaceans. Seafish Report.
Summary: This report was written to support the UK seafood industry when engaging with offshore development proposals that may result in anthropogenic sound, seabed substrate-borne vibration, and Electromagnetic Fields (EMFs). Table 1 provides an overview of the existing literature concerning the effects of these stressors on crustacean species across the world. Most of this work does not cover species of commercial significance in the UK. A key point to note is that most of these studies used sources mimicking the stressor type, rather than exposing individuals to the actual stressor (e.g. boat noise). This literature review highlights the lack of knowledge on the effects of noise, vibration, and EMFs on crustaceans. Limited research with mixed results precludes the ability to draw overall conclusions but highlights the potential for these stressors to have an influence on crustaceans in general and the necessity of future research to identify vulnerable species and life stages.
• Noise studies on UK commercially important crustaceans are very limited. Robust knowledge of known sensitivities to noise and vibration have not been documented, nor have behavioural and physiological changes at different parts of the life cycle. However, the ecosystem engineering behaviours and bioirrigation of the Norway lobster (Nephrops norvegicus) are influenced by shipping and construction noise. In addition, a PhD thesis noted alteration of different aspects of the Norway lobster's larval life cycle in response to shipping noise, which can lead to a reduction in predator avoidance stamina. Shipping noise was also suggested to elicit avoidance behaviour in the European lobster (Homarus gammarus) in another PhD thesis.
• Particle motion (the movement of particles around a sound wave to allow for its transmission) is the aspect of noise most likely detected by crustaceans. A modelling study suggested that particle motion can be detected on the seafloor up to 400 m from a pile driving site.
• Crustaceans have the ability to detect and utilise EMF with a relatively high degree of sensitivity. As a result, environmental fluctuations caused by Marine Renewable Energy Devices (MREDs) may have a multitude of effects on crustacean behaviour and physiology.
• Exposure to EMF has been shown to alter adult edible crab (Cancer pagurus) and European lobster physiology and larval development resulting in significantly smaller size individuals. Circadian rhythms were disrupted in both species, possibly due to increased anaerobic

respiration and potentially the onset of hyperglycaemia - both known responses to stress - although longer term studies are required to confirm this. Edible crabs were affected behaviourally whereby attraction to EMF source potentially overrides natural foraging behaviours, whilst there have been mixed European lobster behaviour results. European lobsters have also shown an immune response to EMF exposure, as observed through a significant change in haemocyte levels.

• It is possible that crustaceans will be exposed to both noise and EMF simultaneously, or within short time periods, particularly surrounding windfarm and other MRED construction and operation. There are currently no research papers looking at the combined effects of noise, vibration, and EMF on crustaceans. Excellent document that describes data gaps, future research needs and highlights the limited number of current studies published on impacts of OSW. Although more studies have been published since 2020, many of them are computer model-based research. The empirical data collected from actual wind farms vs the accuracy, limitations, and assumptions of model data is invaluable.

The Effects of Anthropogenic Electromagnetic Fields (EMF) on the Early Development of Two Commercially Important Crustaceans, European Lobster, Homarus gammarus (L.) and Edible Crab, Cancer pagurus (L.) https://doi.org/10.3390/jmse10050564 Harsanyi, P.; Scott, K.; Easton, B.A.A.; de la Cruz Ortiz, G.; Chapman, E.C.N.; Piper, A.J.R.; Rochas, C.M.V.; Lyndon, A.R.
Abstract: Proposed offshore windfarm sites could overlap with the brooding and spawning habitats of commercially important crustacea, including European lobster, Homarus gammarus and Edible crab, Cancer pagurus. Concerns have been raised on the biological effects of Electromagnetic Fields (EMFs) emitted from subsea power cables on the early life history of these species. In this study, ovigerous female H. gammarus and C. pagurus were exposed to static (Direct Current, DC) EMFs (2.8 mT) throughout embryonic development. Embryonic and larval parameters, deformities, and vertical swimming speed of freshly hatched stage I lobster and zoea I crab larvae were assessed. EMF did not alter embryonic development time, larval release time, or vertical swimming speed for either species. Chronic exposure to 2.8 mT EMF throughout embryonic development resulted in significant differences in stage-specific egg volume and resulted in stage I lobster and zoea I crab larvae exhibiting decreased carapace height, total length, and maximum eye diameter. An increased occurrence of larval deformities was observed in addition to reduced swimming test success rate amongst lobster larvae. These traits may ultimately affect larval mortality, recruitment and dispersal. This study increases our understanding on the effects of anthropogenic, static EMFs on crustacean developmental biology and suggests that EMF emissions from subsea power cables could have a measurable impact on the early life history and consequently the population dynamics of H. Gammarus and C. pagurus. . This is an important study for commercial fishing industry reliant on crustacean harvesting.

Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables U.S. Hutchison, Z. L., P. Sigray, H. He, A. B. Gill, J. King, and C. Gibson, 2018. Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2018-003. In 2014, The University of Rhode Island and key partners were contracted by the Bureau of Ocean Energy Management (BOEM) to conduct a two-year study entitled "Electromagnetic Field (EMF) Impacts on Elasmobranch (sharks, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables." The BOEM-URI project had five major components:

1. A synthesis of existing information published subsequent to the report entitled " Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species" (Normandeau et al., 2011) for BOEM on EMF and the potential effects on marine species;
2. Field surveys to characterize the EMF from two high voltage direct current (HVDC) cables; the Cross Sound Cable (CSC) and the Neptune Cable;
3. A computer model to predict the EMF generated by HVDC cables and a comparison of EMF model predictions with EMF field measurements for validation and to determine if the model could be extrapolated to higher capacity cables that are likely to be installed in the future;
4. A statistically robust field experiment that would detect potential effects of EMF from HVDC cables on the movements of marine species (American lobster, Homarus americanus and Little skate, Leucoraja erinacea) of concern; and
5. An integration, interpretation and evaluation of the multidisciplinary findings

A review of potential impacts of submarine power cables on the marine environment: knowledge gaps, recommendations and future directions. Bastien Taormina, Juan Bald, Andrew Want, Gérard Thouzeau, Morgane Lejart, Nicolas Desroy, Antoine Carlier. Abstract Submarine power cables (SPC) have been in use since the mid-19th century, but environmental concerns about them are much more recent. With the development of marine renewable energy technologies, it is vital to understand their potential impacts. The commissioning of SPC may temporarily or permanently impact the marine environment through habitat damage or loss, noise, chemical pollution, heat and electromagnetic field emissions, risk of entanglement, introduction of artificial substrates, and the creation of reserve effects. While growing numbers of scientific publications focus on impacts of the marine energy harnessing devices, data on impacts of associated power connections such as SPC are scarce and knowledge gaps persist. The present study (1) examines the different categories of potential ecological effects of SPC during installation, operation and decommissioning phases and hierarchizes these types of interactions according to their ecological relevance and existing scientific knowledge, (2) identifies the main knowledge gaps and needs for research, and (3) sets recommendations for better monitoring and mitigation of the most significant impacts. Overall, ecological impacts associated with submarine power cables can be considered weak or moderate, although many uncertainties remain, particularly concerning electromagnetic effects. Many of the studies available in the published literature have been conducted on behalf of a renewable energy proponent or governmental energy department as in this case the authors are.

Risk to Animals from Electromagnetic Fields Emitted by Electric Cables and Marine Renewable Energy Devices. OES-ENVIRONMENTAL 2020 STATE OF THE SCIENCE REPORT. SECTION B – CURRENT KNOWLEDGE OF KEY DEVICE INTERACTIONS WITH THE MARINE ENVIRONMENT Chapter 5, Authors: Andrew B. Gill, Marieke Desender. "..The measurement data needed to validate EMF models are lacking." No studies concerning E-fields in the predictive range associated with MRE devices have been conducted to date, largely because the industry is still emerging and power generation levels are relatively low and isolated, and EMF studies have seldom been required in the marine environment for established industries. This section of the report mentions many relevant recent scientific studies and data gaps.

EFFECTS OF EMFS FROM UNDERSEA POWER CABLES ON ELASMOBRANCHS AND OTHER MARINE SPECIES. Normandeau, Exponent, T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09. Normandeau, Exponent, T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09. Anthropogenic electromagnetic fields (EMFs) have been introduced into the marine environment around the world and from a wide variety of sources for well over a century. Despite this, little is known about potential ecological impacts from EMFs. For decades, power transmission cables have been installed across bays and river mouths, and connecting near-shore islands to the mainland, with little consideration of possible effects to marine species from EMFs. At a time of greater environmental awareness, the US now faces the possibility of a new source of EMFs over a much greater extent of the seabed from offshore renewable energy facilities in coastal waters. This literature review synthesizes information on the types of power cables and models the expected EMFs from representative cables. Available information on electro- and magnetosensitivity of marine organisms, including elasmobranchs (sharks and rays) and other fish species, marine mammals, sea turtles, and invertebrates is summarized and used in conjunction with the power cable modeling results to evaluate the level of confidence the existing state of knowledge provides for impact assessment. Gaps in our knowledge of power cable characteristics and the biology needed to understand and predict impacts are summarized and form the basis of recommendations for future research priorities. Potential mitigation opportunities are described with a discussion of their potential secondary impacts as well as suggested methods for monitoring mitigation effectiveness. Finally, because interest in offshore renewable energy has increased throughout US coastal waters, there is a concern that organisms could be exposed to multiple seabed power cables. Cumulative effects of this exposure are discussed.

Effects of Electromagnetic Fields on Fish and Invertebrates Task 2.1.3: Effects on Aquatic Organisms Fiscal Year 2011 Progress Report, Environmental Effects of Marine and Hydrokinetic Energy , DL Woodruff JA Ward, IR Schultz VI Cullinan, KE Marshall May 2012 Prepared for the

U.S. Department of Energy under Contract DE-AC05-76RL01830 Pacific Northwest National Laboratory. Richland, Washington 99352. Abstract: This fiscal year (FY) 2011 progress report (Task 2.1.3 Effects on Aquatic Organisms, Subtask 2.3.1.1 Electromagnetic Fields) describes studies conducted by PNNL as part of the DOE Wind and Water Power Program to examine the potential effects of electromagnetic fields (EMF) from marine and hydrokinetic (MHK) devices on aquatic organisms, including freshwater and marine fish and marine invertebrates. In this report, we provide a description of the methods and preliminary results of experiments conducted in FY 2010–FY 2011 to evaluate potential responses of selected aquatic organisms. Preliminary EMF laboratory experiments during FY 2010 and 2011 entailed exposures with representative fish and invertebrate species including juvenile coho salmon (Oncorhynchus kisutch), Atlantic halibut (Hippoglossus hippoglossus), California halibut (Paralicthys californicus), rainbow trout (Oncorhynchus mykiss), and Dungeness crab (Metacarcinus magister). These species were selected for their ecological, commercial, and/or recreational importance, as well as their potential to encounter an MHK device or transmission cable during part or all of their life cycle. EMF intensities during the various tests ranged between approximately 0.1 and 3 millitesla, representing a range of expected upper bounding conditions that might be encountered at a field location, according to values currently reported in the literature. Based on previous studies, acute effects such as mortality were not expected to occur from EMF exposures. Therefore, our measurement endpoints focused on developmental changes (i.e., growth and survival from egg or larval stage to juvenile), exposure markers indicative of physiological responses, or behavioral responses (e.g., detection of EMF, interference with feeding behavior, avoidance or attraction to EMF) for the various species. Data analysis is still in progress, however preliminary results to date have shown few statistically significant laboratory responses to elevated EMF intensities for the aquatic species and endpoints tested. Further testing and replication is needed to verify and expand on these results. Additional species are currently planned for laboratory testing in the next fiscal year (e.g. American lobster, an elasmobranch) to provide a broader assessment of species important to stakeholders. A concern with using this study for offshore wind in Nova Scotia, authors used an EMF strength of 3 mT, we have no definitive information about expected EMF levels from a 15MW turbine or a 300MW wind farm. Experiments with Atlantic halibut suggested that a high EMF exposure may have reduced both growth and development in early life stages, although neither was statistically different from the controls. This halibut experiment experienced a high mortality rate with 80% mortality by end of experiment. Therefore, animals that were assessed during this study were less than 30 fish. Experiments with California halibut showed no change in growth or development. Developmental experiments using rainbow trout addressed the potential exposure of fertilized eggs to transmission cables in riverine settings. There was no apparent affect on fertilization success rate. Although not statistically significant, exposure of fertilized trout eggs to EMF for extended periods appeared to delay the rate of egg development. The salmonid alarm response endpoint was inconclusive, concurrent exposure marker experiments showed no evidence of stress as measured by levels of cortisol in juvenile salmon. Decreases in melatonin levels, involved in smoltification of salmonids (Gern et al. 1984), were observed, however were not statistically significant. During Dungeness crabs EMF exposure, antennular flicking rate decreased slightly but was not significantly different from rates measured before EMF exposure. Likewise, the flicking rate response to a food odor decreased slightly after exposure to EMF but was not statistically significant. Initial avoidance/attraction experiments have shown some evidence of subtle changes in behavior (e.g., amount of time buried, number of changes and variability in activity through time). However, these results are preliminary, and replication of the experiments and further analysis of the data are warranted to understand their meaning. The potential effect of EMF on fertilized eggs is concerning to us. We would love this study to be repeated and see if reproducibility occurs.

6. Socioeconomic

Socioeconomic impact study of offshore wind. DANISH SHIPPING, WIND DENMARK AND DANISH ENERGY WITH SUPPORT FROM THE DANISH MARITIME FOUNDATION July 1st, 2020 Final Technical Report

Workshop on socio-economic Implications of Offshore Wind on Fishing Communities (WKSEIOWFC) ICES. 2021. Workshop on Socio-economic Implications of Offshore Wind on Fishing Communities (WKSEIOWFC). ICES Scientific Reports. 3:44. 33 pp. https://doi.org/10.17895/ices.pub.8115. Section 6, page 18. **Conclusion and Recommendations** - Developing best practices in managing fisheries & OWF interactions. WKSEIOWFC demonstrated the importance of improving our understanding of the socio-eco-nomic implications of OWF and fisheries interactions. The event was attended by participants from nine countries who represented policy/regulation, the fishing and OWF industries, consultants and academia.

The workshop allowed us to describe, summarise and illustrate perceptions of the various potential environmental, economic and cultural effects that offshore wind development may have on fisheries. Moreover, we were able to highlight the complexity and interconnectedness of the issues under discussion.

We further explored common issues between European and US regions such as complex inter-actions of new OWF technologies in combination with traditional fisheries that are strongly linked to the identity of coastal communities. Similarities identified across regions such as lacking integrated, appropriately-scaled and commonly-defined fisheries assessment frameworks, as well as the scientific uncertainty associated with surveys beyond the turbine scale, helped us to define issues that need to be addressed in the future. In addition, key differences were identified between European and US regions, noting that intra-regional differences exist within Euro-pean jurisdictions and within US regions. Notable key differences include the policy and governance structures both for offshore wind permitting and for fisheries management; fisheries in Europe have a longer history of interacting with installed wind projects than fisheries in the US and this may contribute to greater perceived uncertainty in US; further, the scale and cultural significance of fisheries in general is much greater in some geographic regions than in others.

Evidence and data gaps were mostly related to identifying thresholds for positive and negative impacts, the acceptability and feasibility of co-location and the fishers' responses to displacement. The latter is particularly important as the fishers' behaviour can be driven by social factors such as working rhythm (Schadeberg et al. 2021), which need to be understood in order to assess the real impact of OWF development on fisheries.

An expanded, future effort should further explore the three-dimensionality of effects we describe in our conceptual representation of the interactions between environmental, economic and social/cultural changes, and how these different elements were partitioned into the three main workshop themes (Fig. 1). Further, it needs to address the effect of multiple OWF, the effects of OWF in combination with other human and external drivers of change (while likely not an exhaustive list, some examples provided during the workshop included shipping and transport, climate change, or the COVID-19 pandemic).

In conclusion, more research is needed to assess potential impacts of the development of OWF on the fishing sector, fishing communities and economic activities onshore. The results of this workshop will be carried further as the WGOWDF addresses its ToR A. This will include the following efforts: further analyse, review, and summarise the results of mental models, identify linkages between different model dimensions, evaluate and identify metrics for measuring important factors and conditions for each of the sub-models, and identify and prioritise where there are data gaps requiring new research. This understanding can be used to foster information exchanges, collaboratively address science questions, and support decision-making. These activities are considered to have a very high priority on a global level, especially as offshore wind energy expands.

Making Waves: THE ECONOMIC CONTRIBUTION OF THE SEAFOOD INDUSTRY TO NOVA SCOTIA. Pisces Consulting Limited October 2022. Most recent economic data for fishery in Nova Scotia. We suggest an economic impact assessment for Atlantic Canadian fisheries report be prepared for 5GW offshore wind capacity in NS.